Dark Energy Survey Project
Calibrations

Plan for Calibration of the DES in the Early Years

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1 Introduction

In this document, we will briefly discuss the 5-year calibration plan (Section 2), the special constraints of DES Science Verification (SV) and of DES Years 1 and 2 (Section 3), and a detailed list of procedures for nightly/weekly/monthly/yearly calibrations procedures with special reference to these early-year needs (Section 4). Here, and throughout this document, DES Year 1 refers to the first year of DES survey operations, currently slated to start in September 2013, and DES SV refers to the November 2012-February 2013 period in which the scientific quality of DECam outputs were being tested in preparation for the survey proper.[1]

2 The 5-Year DES Calibration Plan: A Brief Overview

Recall that the DES 5-year photometric calibration requirements (DES-doc#20-32[2]) are the following:

- All-sky internal requirements (R-6 & R-10): 2% rms (goal: 1% rms)
- Absolute color calibration (R-11 & R-13): 0.5% (*g-r, r-i, i-z*); 1% (*z-Y*) [averaged over 100 objects scattered over the focal plane]
- Absolute flux calibration (R-12): 0.5% in *i*-band [relative to BD+17 4708]

The 5-year DES calibration plan depends strongly on the general DES observing strategy. The basic observing strategy is to perform multiple, offset tilings (layers) over the survey footprint over the course of the 5-year program (Figure 1). The multiple, offset tilings (Figure 2) permit the DES to achieve its all-sky internal (relative) photometric requirements. The connection to SDSS Stripe 82 provides an important step for achieving DES's absolute color and absolute flux requirements. (The final absolute color and flux calibration of the DES, however, will be accomplished, respectively, by direct measurements of BD+17 4708 and by observations of a "Golden Sample" – which will be established over the course of the next few years – of about 100 DA White Dwarfs and other spectrophotometric standards scattered throughout the DES footprint.)

[1] Strictly speaking, SV was confined to November 2012, and the period of December 2012-February 2013 was referred to as *extended* SV, but, here, for simplicity, we refer to whole November 2012-February 2013 periods as SV.

[2] http://des-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=20&version=32

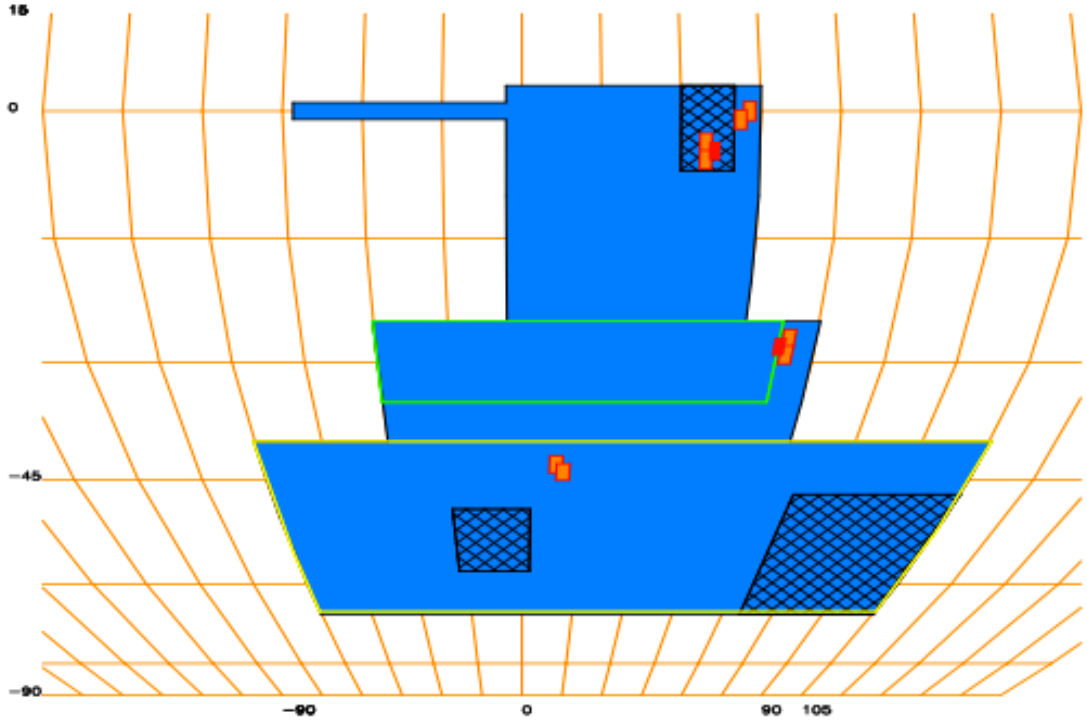

Figure 1: DES footprint (v2012-09-27). The DES 5-year (blue) and originally planned SV footprints in a Putnins IV equal area projection. RA increases to the right. Hatched regions show the originally planned 10-tiling depth areas of the SV season equatorial "mini-survey" and SPT-West and SPT-East regions; red/orange squares are the SN fields. Also shown are the SPT SZE survey area (yellow outline) and the Viking VISTA survey area (green outline). The overlap with SDSS Stripe 82 (at DEC=0 deg) supplies the DES with not only photo-z calibration fields, but also a large number of faint (r > 14.5), well-calibrated faint standard stars from the SDSS (Ivezic et al. 2007; Betoule et al. (2012, arXiv:1212.4864). The connector region provides a continuous link between the calibration fields in SDSS Stripe 82 and the main survey region. (Credit: J. Annis).

Figure 2: Tiling strategy for the DES. Each hexagon represents the footprint of the DECam focal plane and is 2.2 deg across (3.1 sq deg in area). The leftmost figure illustrates a small section of 7 pointings within the first tiling of the DES footprint. The middle figure shows the location of the pointings for the second tiling – offset half a focal plane ("hex") to the right and half a focal plane up. The rightmost figure shows the location of the pointings for the third tiling.

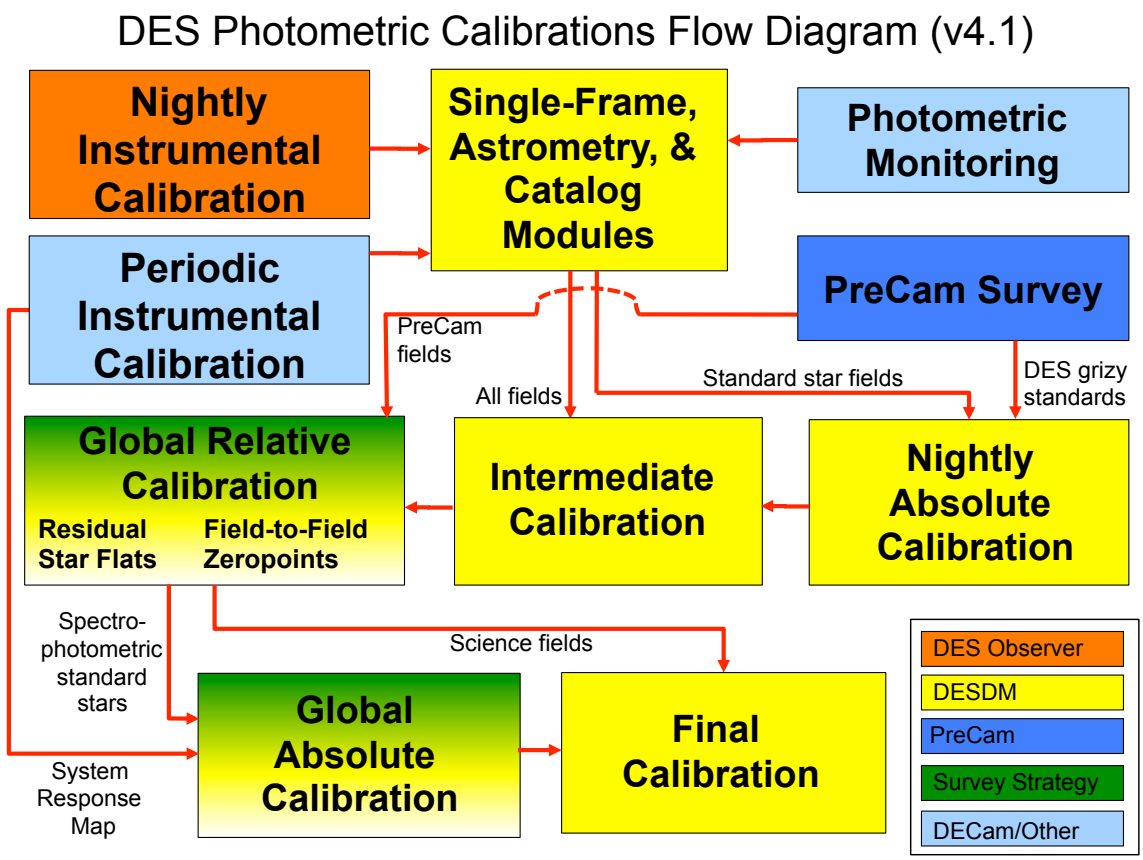

Figure 3: Flow diagram of the DES Calibrations Plan. (Color coding indicates areas of responsibility within the DES project.)

Exposure times for DES wide-survey science fields will be typically between 80 and 100 seconds (longer for the SN fields). The current plan is to observe 2 or 3 filters for each pointing (*g* and *r* in dark time, and *i, z,* and *Y* in bright time), and to cover the full DES footprint with 2 tilings per filter per full DES year.

A flow diagram of the DES Calibrations Plan can be found in Figure 3. Basically, it can be summed up in 7 points:

1. **Instrumental Calibration (Nightly & Periodic):** Create biases, dome flats, linearity curves, cross-talk coefficients, DECal system response maps.
2. **Photometric Monitoring:** Monitor sky with the 10μm all-sky cloud camera (RASICAM; see Figure 4) and other external systems (GPS water vapor monitor, aTmCam atmospheric transmission monitor).
3. **PreCam Survey:** Create a network of calibrated DES *grizY* standard stars for use in nightly calibrations and in DES Global Relative Calibrations (Figure 5).
4. **Nightly and Intermediate Calibrations:** Observe standard star fields with DECam during evening and morning twilight and (perhaps) once in the middle of the night; fit photometric equation; apply the results to the data. (An initial set of standard star

fields is provided in Appendix A; see also Figure 5. See Appendix B for a description of the functional form of the nightly photometric equation.) In addition, DECam will serendipitously scan across PreCam-calibrated fields multiple times throughout a typical night in process of normal DES science targeting.

5. **Global Relative Calibrations:** Use the extensive overlaps between exposures over multiple tilings to tie together the DES photometry onto an internally consistent system across the entire DES footprint. The grid of PreCam fields will provide a rigid grid of standards to anchor the solution against systematic errors in the global relative calibrations across the DES footprint.
6. **Global Absolute Calibrations:** Use DECam observations of spectrophotometric standards (the "Golden Sample" of DA White Dwarfs and other spectrophotometric standards) in combination with measurements of the full DECam system response map from the DECal system to tie the DES photometry onto an AB magnitude system.
7. **"Final" Calibration:** Applying the 5 offsets (one for each of the DES *grizY* filters) to the data, to tie the DES photometry to the AB magnitude system (which is a tie to physical specific flux units of ergs/s/cm^2/Hz).

Note that the steps through Intermediate Calibrations can be performed as the data arrive – basically as each night of data is obtained and transferred to NCSA. The steps from Global Relative Calibrations onward are expected to be performed after each DES season is finished. *These seasonal calibrations are expected to be an iterative process, with the truly final "Final Calibrations" only occurring at the end of the survey.*

For further details of the 5-year DES calibration plan, please consult Tucker et al. (2007) and Tucker et al. (in preparation).[3]

[3]Tucker et al. (in prep.) is the conference proceedings write-up of the following talk given at the "Calibration & Standardization of Large Surveys and Missions in Astronomy & Astrophysics" conference held at Fermilab April 16-19, 2012:
https://indico.fnal.gov/getFile.py/access?contribId=8&sessionId=8&resId=0&materialId=slides&confId=4958
A slightly outdated (from April 2010) but more detailed presentation can be found here:
http://des-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=4378

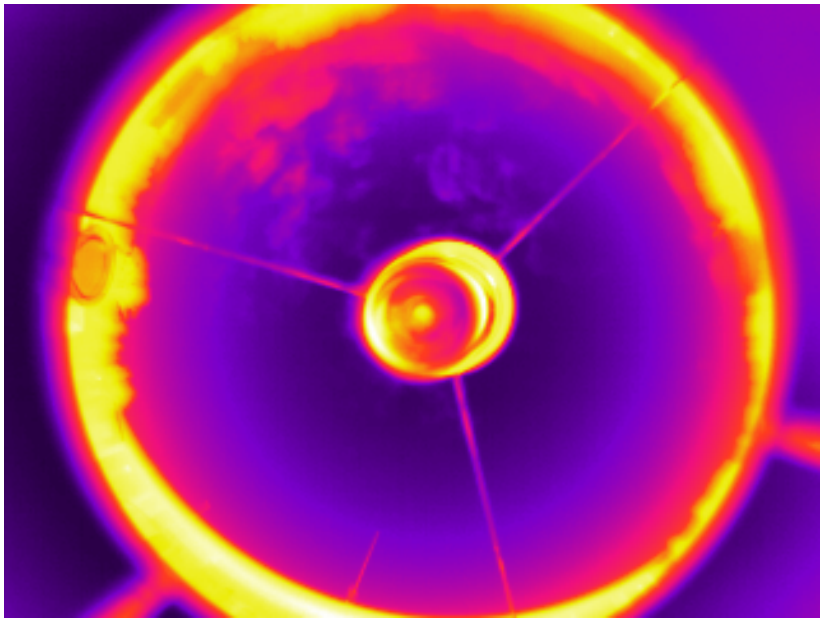

Figure 4: Image from the RASICAM 10-micron all-sky camera. Note the cirrus visible in the top half of the image between 2 vanes of the 3-vaned secondary support structure. (Credit: Peter Lewis, K. Reil, and Rafe Schindler)

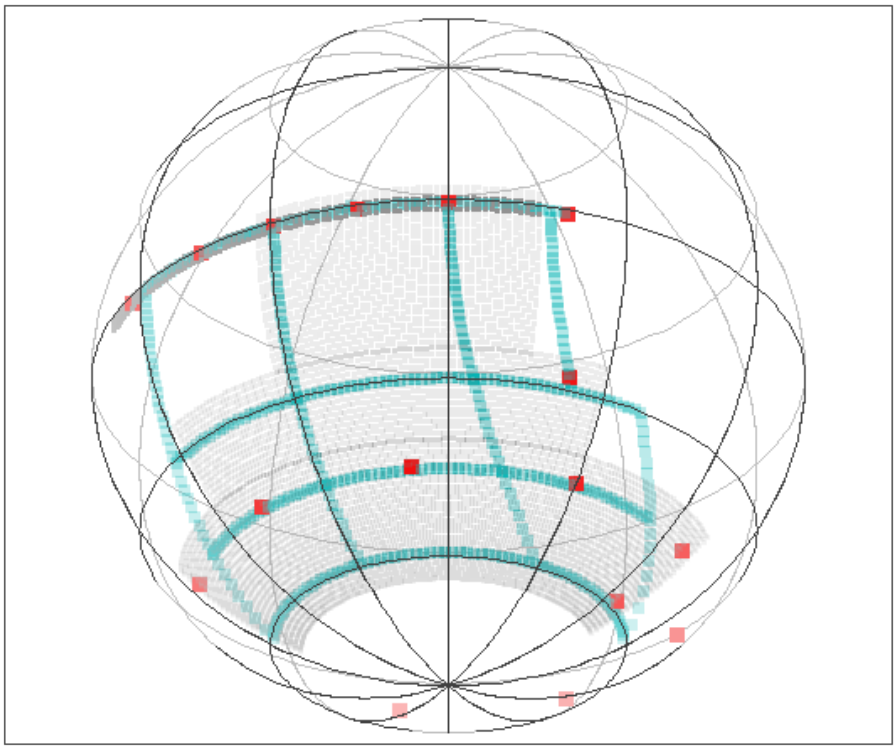

Figure 5: The DES footprint (light gray) and standard star fields available for DES projected onto a sphere with a coordinate grid in RA,DEC. The dark gray indicates DES hexes overlapping SDSS Stripe 82, the cyan fields indicate the PreCam footprint as originally planned (it is only about half-way completed at this point (see, e.g., Figure 6), and the red squares indicate the positions of the DES nightly standard star fields from Appendix A.

3 The Special Constraints of DES Science Verification and Year 1 & 2 Operations

For the most part, the calibration plan for DES SV and for Years 1 & 2 follows that for the 5-year plan. There is a strong desire, however, to try to achieve as close to the 5-year calibration requirements as soon as possible, for at least a subset of the DES area, in order to enable early science. A major reason for performing the PreCam Survey is to help achieve the DES calibration requirements and goals earlier than would be otherwise be possible using DECam alone.

3.1 DES Science Verification Data

Special constraints for calibrating the DES Science Verification Data:

1. The DECam CCD or set of DECam CCDs (e.g., an area-weighted average over the full DECam focal plane) that will be used to define the DECam "natural" system has yet to be established.

2. During DES SV, for the DES wide-area survey, two large-ish disconnected "islands" were observed, both in the South Pole Telescope (SPT) area: a western region (SPT-West) covering c. 60 sq deg around RA,DEC=353°,-55° observed to about a 3-year depth (c. 6 tilings), and an eastern region covering c. 175 sq deg around RA,DEC=75°,-55° observed to about a full 5-year depth (c. 10 tilings); see Figure 6. In addition, an area of the equatorial "mini-survey" was observed (although the image quality is such that these data will probably not be used in the SV science analysis), as well as two special galaxy cluster fields (the Bullet Cluster and the "El Gordo" Cluster.) It will be a challenge to tie these two disconnected "islands" – as well as these other science fields – together photometrically at the level desired in all 5 DES bandpasses (due primarily to the following item).

3. Due to various problems, the PreCam Survey was not completed.[4] In particular, only *i*-band is complete in the region that was covered in DES SV, although there is also moderate PreCam coverage in this region in the *g*- and *r*-bands. (Unfortunately, due to time constraints, PreCam only observed target fields in SDSS Stripe 82 in the *z*- and *Y*-bands. That said, we might be able to use some of the short-exposure standard star fields that were observed for calibrating PreCam: they were observed in all 5 DES filters, including *z* and *Y*, and several of them lie within the SPT section of the DES footprint.)

4. There is still a lack of DES *Y*-band standards outside of the area already covered by PreCam (a section within SDSS Stripe 82). Currently, we supplement this lack by

[4] The Calibrations Group is investigating a proposal to the DES Collaboration for a second campaign of the PreCam Survey, of approximately 100 nights, during the early years of DES operations, to complete the original goals of the PreCam Survey.

using UKIDSS LAS *Y*-band data in the SDSS Stripe 82 area. We also hope to be soon able to make use of the PanSTARRS *grizy* standard star catalog – a catalog that extends over the sky north of DEC=-30° – once it becomes publicly available (expected by mid-2013).

5. The "Golden Sample" of DA White Dwarfs is currently a work in progress (and will possibly be hampered by curtailed SMARTS operations), and it will not be ready in time for DES SV or probably even for DES Year 1. (The "Golden Sample" is an iterative effort to create an ever-improved sample, and the final version will likely only be available for DES Year 5).

6. Several issues were discovered during DECam Commissioning and Science Commissioning of particular import to photometric calibrations – in particular, non-linearities in the CCD responses and not-yet-full understood scattered light and spatially non-uniform variations in the system response of the different filters. It will take some time to understand these issues fully and to correct for them.

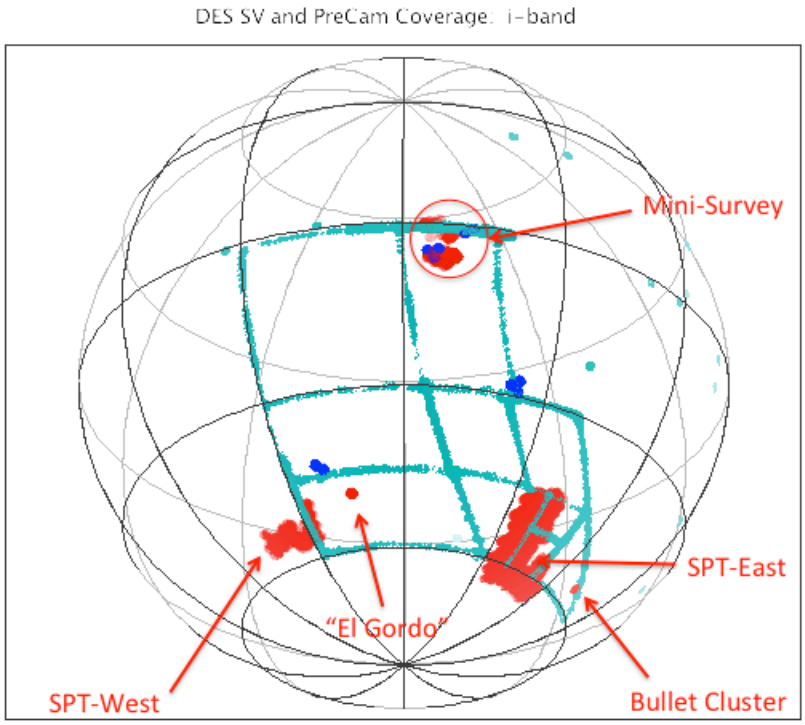

Figure 6: Actual *i*-band RA,DEC coverage of the DES SV wide-field regions (red), of the DES SN fields (blue), and of the PreCam standards (cyan). The DES SV SPT regions are centered near RA,DEC=353°,-55° (SPT-West) and RA,DEC=75°,-55° (SPT-East). The current sets of PreCam *g*- and *r*-band data have coverage similar to that of the *i*-band, but spottier; the current set of PreCam *z*- and *Y*-band data are confined primarily along SDSS Stripe 82.

Special plans for calibrating the DES Science Verification Data:

1. For early data processing of the SV fields, until we fully understand the DECam filter passband system responses and define which CCD or set of CCDs define the DECam "natural system", we will calibrate roughly to the SDSS *griz* (and UKIDSS Y_{ab}) system (calibrating to SDSS zeropoints for an "average color" star, but ignoring color terms). As we understand the DECam filter passband system responses better (via the DECal instrumental response scans), we will be able to move over to calibrating to a true DES "natural" photometric system.

2. To connect the two "islands" (and other science wide field survey science fields) photometrically:
    a. use the nightly standard star calibrations for exposures taken in each of these islands during photometric conditions; and/or
    b. connect the two "islands" with directly PreCam standard stars (possible for *g,r,i*, but not *z,Y*); and/or
    c. if necessary, use the Stellar Locus Method (High et al. 2009).

3. To deal with the relative lack of DES *Y*-band standards:
    a. use UKIDSS LAS *Y* data (converted to the AB mag system) as a proxy, and
    b. use the PanSTARRS y-band standards once they become available.

4. The SDSS Stripe 82 standards, the UKIDSS LAS Y_{ab} data, the PreCam standards, and the PanSTARRS standards – especially once transformed to the DECam "natural" system – will provide adequate absolute calibration for the SV data. Furthermore, a handful of HST CalSpec spectrophotometric standards were observed as a part of DECam Commissioning and SV, and these observations will also help in the absolute calibration of the DECam "natural" system. It possible, too, that a "Bronze Sample" DA White Dwarfs within the DES equatorial stripe (SDSS Stripe 82) will also be able to be used by the start of DES operations.

For DES SV, we conservatively expect to achieve the following levels of calibration in the SPT-West and SPT-East regions:

- All-sky internal requirements: 3% rms overall for fields observed under photometric conditions or directly tied photometrically to other fields observed under photometric conditions, and even better in the 10-tiled regions (this value is dependent primarily on our understanding of effects of diffuse scattered light and other flat fielding issues)

- Absolute color calibration: 3% (*g-r, r-i, i-z*); 4% (*z-Y*)
  [averaged over 100 objects scattered over the focal plane]

- Absolute flux calibration: 3% in *i*-band (relative to BD+17 4708)
  [we actually observed BD+17 4708 directly with DECam during DECam commissioning, as well as observed calibration fields in SDSS Stripe 82 (recall that SDSS uses BD+17 4708 as its fundamental standard star.]

3.2 DES Year 1

Special constraints for Year 1:

1. The default plan for DES Year 1 is to observe 2 tilings of the full DES footprint in each of the 5 DES filters (*grizY*); thus, there will generally only be 2 tilings covering the DES footprint, and, thus, the internal photometric calibrations will not be very robust against data taken under non-photometric conditions.

2. There is a lack of completed PreCam data over the full DES footprint (especially in *z* and *Y*).

3. The White Dwarf "Golden Sample" will likely still be in development.

Special plans for DES Year 1:

1. To deal with the relatively small number of tilings (typically 2 tilings per filter):
   a. use RASICAM "photometricity" flag to determine which images are photometric (during the typical DES season at CTIO – September through January, a large majority of images will be photometric), and use this information to directly calibrate non-photometric images against photometric ones, and
   b. use the available grid of PreCam standards (at least for *g,r,i*) to help tie down the global calibrations of the DES data (see item 2 below), and/or
   c. if necessary, use the Stellar Locus Method (High et al. 2009).

2. If resources are available, and if the DES agrees to support it, proceed with a second campaign of PreCam.

3. To supplement the current number of DES *Y*-band standards:
   a. use UKIDSS LAS *Y* data (converted to the AB mag system) as a proxy, and
   b. use the PanSTARRS y-band standards once they become available.

4. Build upon the absolute calibrations from the SV data by using a "Bronze (Silver?) Sample" made up of DA White Dwarfs with modeled spectrophotometry from SDSS

DR8 (which just covers the northern part of the DES) plus any available from the continuing White Dwarf follow-up program based on the Rowell & Hambly (2011) proper motion catalog of candidate White Dwarfs (co-leads: J. A. Smith and W. Wester).

For DES Year 1, we conservatively expect to achieve the following levels of calibration over the full DES footprint (note that the values are the same as for the SV data, but here cover the full DES footprint instead of two heavily tiled "islands"):

- All-sky internal requirements: 3% rms overall for fields observed under photometric conditions or directly tied photometrically to other fields observed under photometric conditions.

- Absolute color calibration: 3% (*g-r, r-i, i-z*); 4% (*z-Y*) [averaged over 100 objects scattered over the focal plane]

- Absolute flux calibration: 3% in *i*-band (relative to BD+17 4708)

3.1 DES Year 2

Special constraints for Year 2:

1. Generally, there will only be 4 tilings covering the DES footprint.

2. There is a lack of completed PreCam data over the full DES footprint (especially in *z* and *Y*).

3. The White Dwarf "Golden Sample" will likely still be in development.

Special plans for Year 2:

1. To deal with the relatively small number of tilings (typically 4 tilings per filter):
    a. use RASICAM "photometricity" flag to determine which images are photometric (during the typical DES season at CTIO – September through January, a large majority of images will be photometric), and use this information to directly calibrate non-photometric images against photometric ones, and

b. use the available grid of PreCam standards (at least for *g,r,i*) to help tie down the global calibrations of the DES data (see item 2 below), and/or
c. if necessary, use the Stellar Locus Method (High et al. 2009).

2. If resources are available, if the DES agrees to support it, and if PreCam is still not completed, proceed with an additional campaign of PreCam. (Beyond DES Year 2 or 3, it is expected that the benefits of completing PreCam become marginal; and so it would be unlikely we would pursue PreCam observations much beyond DES Year 2.)

3. A White Dwarf "Bronze-Plus" or a "Silver Sample" should be ready by DES Year 2.

4 A Detailed List of Periodic and Special-Case Calibration Procedures during DES Operations

This is a list of periodic and special-case calibration procedures for the DES operations. Although iterated over during the course of the DES SV, it is likely that details of this list may still evolve as we become more familiar with the performance of the DECam over time.

4.1 Daily

1. Afternoon

   a. 25 bias frames

   b. 60 dome flats, composed of:
      i. 10 dome flats in *g* (30 sec each)
      ii. 10 dome flats in *r* (10 sec each)
      iii. 10 dome flats in *i* (22 sec each)
      iv. 20 dome flats in *z* (10 sec each)
      v. 10 dome flats in *Y* (10 sec each)

   [exposure times were determined during Commissioning and SV]

2. Evening Twilight

   a. 3 standard star fields, starting about 45 minutes before Astronomical (18°) Twilight (c. 10 minutes after the end of Civil (6°) Twilight).
      i. 1 at low airmass (X=1.0-1.25)
      ii. 1 at intermediate airmass (X=1.25-1.65)
      iii. 1 at high airmass (X=1.65-2.10)

iv. At least one of these fields must be in SDSS Stripe 82 in order to achieve full coverage of all CCDs in the DECam focal plane.
v. Positions and exposure times of nightly standard star fields can be found in Appendix A.
vi. Skip if thick clouds are present.

3. Night

a. 1 standard star field around night's midpoint (c. 1AM local time), or just before switchover when DES is allocated the first half of the night.
i. Preferably at high airmass (X=1.65-2.10).
ii. Preferably should be a field SDSS Stripe 82 in order to achieve full coverage of all CCDs in the DECam focal plane.
iii. Positions and exposure times of nightly standard star fields can be found in Appendix A.
iv. Skip if thick clouds are present.

b. 10-micron cloud camera photometricity measurements
i. These will be obtained throughout the night by RASICAM and are automatically added by SISPI to the FITS headers of exposures taken by DECAM.

c. GPS station precipitable water vapor measurements
i. The GPS station will make these measurements automatically throughout the night and the results will made available over the web by Suominet within a few days; the results will also be ingested into the DESDM database *(details to be confirmed)*.
ii. Note that the GPS system has already been installed and operating (since early November 2012). It is mounted on the CTIO-1.5m telescope's balcony.

d. aTmCam atmospheric transmission measurements
i. The aTmCam will make these measurements automatically throughout the night and the results will be ingested into the DESDM database *(details to be confirmed)*.
ii. Note that an aTmCam prototype was tested at CTIO during November 2012. DES and CTIO have not yet made a final decision on whether to install a permanent aTmCam on Tololo.

4. Morning Twilight

a. 3 standard star fields, starting about 20 minutes after Astronomical (18°) Twilight (c. 10 minutes before Nautical (12°) Twilight).
i. 1 at low airmass (X=1.0-1.25)

ii. 1 at intermediate airmass (X=1.25-1.65)
iii. 1 at high airmass (X=1.65-2.10)
iv. At least one of these fields must be in SDSS Stripe 82 in order to achieve full coverage of all CCDs in the DECam focal plane.
v. Positions and exposure times of nightly standard star fields can be found in Appendix A.
vi. Skip if thick clouds are present.

4.2 Weekly

1. Quick Star Flats (for monitoring purposes)

    a. These basically come for free whenever we observe Stripe 82 under photometric conditions (almost nightly), because Stripe 82 is already calibrated so we can get a quick star flat accurate to the 1-2% level just by comparing the difference of the observed magnitudes and the calibrated magnitudes against position on the DECam focal plane. In fact, QA outputs from the DESDM pipeline already permit a visual check of this.

4.3 Monthly

2. DECal System Response Measurements

    a. Since these measurements require a very dark dome and take about 4 hours to complete, they will be performed about once a month, on cloudy nights (which occur about once a month in the September – January time frame at CTIO).

3. Dark Frames, composed of:
    a. 10 science-length exposures (typically 100 sec each)
    b. 10 faint-standards-length exposures (typically 30 sec each)
    c. 10 bright-standards-length exposures (typically 5 sec each)
    d. 30 deep-SN-length exposures
        i. 10 200-sec exposures
        ii. 10 300-sec exposures
        iii. 10 400-sec exposures

4. Photon Transfer Curves (a.k.a., Linearity Tests)

    a. Dome-flat-based
        i. Without changing the dome flat lamp intensity, take a series of exposures in a single filter from short to long, interspersed with 10-

sec-long exposures (to account for any variability in the dome flat lamp intensity over time)
[e.g., 10sec-1sec-10sec-2sec-10sec-3sec-10sec-4sec-10sec-5sec-10sec-6sec-10sec-7sec-10sec-8sec-10sec-10sec-10sec-11sec-10sec-12sec-10sec-...(until saturation, which is about 35 sec at current lamp levels)]

b. Star-based
    i. Observe in a single filter under photometric conditions a given star field with known SDSS magnitudes (e.g., in SDSS Stripe 82) in a series of exposures with increasing exposure length [e.g., 1-sec, 3-sec, 10-sec, 30-sec, 100-sec]
    ii. Note: under good conditions, an r=18 magnitude star should only saturate after about 7 minutes of exposure time.

5. Gain, readnoise, and saturation level tests

    a. Note: a quick check of gain and readnoise can be performed on the normal daily data (from the bias frames and dome flats taken each afternoon).

6. Bad pixel map measurements
    a. Compare short and long dome flat exposures.

7. "Victim" (cross-talk) exposures
    a. Observe a field with lots of bright stars (e.g., a nearby open cluster)

8. Intermediate Star Flats

    a. Intermediate to the weekly Quick Star Flats (used for quick visual monitoring of the photometric precision across the DECam field-of-view) and the time-consuming yearly dithered Star Flats (used for creating definitive pupil ghost and star flat corrections), the intermediate star flats make use of a reduced dither pattern (compared to the yearly Star Flats) for a relatively quick internal measurement of the pupil ghost and the star flat correction to monitor against changes from the yearly Star Flat.

9. Fringe frames for z and Y bands
    a. No special observations are necessary – these will be produced from science frames in these two filters.

4.4 Yearly

1. Shutter timing tests

    a. Dome-flat-based

i. Without changing the dome flat lamp intensity, take a series of exposures in a single filter from long (e.g., 100 sec) to short (e.g., 0.1 sec), roughly halving the exposure time between sets of exposures (e.g., one 100-sec exposure, two 50-sec exposures, four 25-sec exposures, ten 10-sec exposures, twenty 5-sec exposures, fifty 2-sec exposures, …)

b. Star-based
   i. Observe in a single filter under photometric conditions a given star field with known SDSS magnitudes (e.g., in SDSS Stripe 82) in a series of exposures with increasing exposure length (e.g., 1-sec, 3-sec, 10-sec, 30-sec, 100-sec); this is the same as the star-based photon transfer curve (linearity test) measurement.

2. Dithered Star Flats
   a. These take a long time but provide better results than the nightly Quick (which occur about once a month in the September – January time frame at CTIO).
   b. Must be done under photometric conditions.
   c. Must be done for all DES filters (but not necessarily all DES filters on the same night).
   d. Can also be used for mapping the astrometric distortions across the focal plane.

4.5 Special Cases/Failure Modes

1. If a CCD or amplifier "dies" and is replaced:

   a. Make measurements of linearity, readnoise, and gain for new CCD/amplifier and all the other CCDs/amplifiers on the focal plane.
   b. Measure linearity for new CCD and all the other CCDs/amplifiers on the focal plane.
   c. Take "victim" (cross-talk) exposures for **all** CCDs, including the new one.
   d. Perform a new set of DECal system response measurements.
   e. Create a new bad pixel map.
   f. Perform a new dithered star flat.

2. If a filter breaks and is replaced:

   a. Re-calculate instrumental color term ("*b*") coefficients with the Photometric Standards Module at next photometric night (unless we choose to "fix" the values of the color term coefficients with fiducial values instead of solving for them nightly, these will be calculated automatically by default).
   b. Perform a new set of DECal system response measurements for the replaced filter.
   c. Re-measure both the Quick and the Dithered Star Flats for the replaced filter.

3. If the shutter fails and is repaired/replaced:

    a. Re-do both the dome-flat-based and the star-based shutter timing maps

Appendix A: Coordinates and Exposure Time for Standard Star Fields for Nightly Photometric Calibrations

Here, we consider those fields that, each night, will be observed specifically for the evening twilight, middle of the night, and morning twilight dedicated standard star field observations. In addition to these fields, the DECam science exposures will serendipitously scan across several PreCam fields during a night as part of normal science target observations.

The list of nightly standard star fields is listed in Table 1. These were the fields determined for use during Science Verification. At attempt was made to keep the number of fields small, so these fields would be observed many, many times and provide as much as possible a single consistent calibration over the course of the survey.

Table 1: List of DES Nightly Standard Star Fields

Field Name	**RA** [J2000]	**DEC** [J2000]	**Exposure Time [sec]**					
			u	g	r	i	z	Y
Main Fields[a]								
SDSSJ2140-0000	21:40:00	+00:00:00	30	15	15	15	15	20
SDSSJ2300-0000	23:00:00	+00:00:00	30	15	15	15	15	20
SDSSJ0000-0000	00:00:00	+00:00:00	30	15	15	15	15	20
SDSSJ0100-0000	01:00:00	+00:00:00	30	15	15	15	15	20
SDSSJ0200-0000	02:00:00	+00:00:00	30	15	15	15	15	20
SDSSJ0320-0000	03:20:00	+00:00:00	30	15	15	15	15	20
C26202/HST[b]	03:32:30	-27:46:05	30	15	15	15	15	20
MaxVis	06:30:00	-58:45:00	30	15	15	15	15	20
Supplementary Fields[b,c]								
E1-A	01:24:50	-44:33:40	10	3	3	3	3	5
E2-A	04:03:00	-44:41:45	10	3	3	3	3	5
E3-A	06:42:54	-45:05:06	10	3	3	3	3	5
E4-A	09:23:44	-45:21:02	10	3	3	3	3	5
E5-A	12:04:11	-45:24:03	10	3	3	3	3	5
E6-A	14:45:33	-45:15:34	10	3	3	3	3	5
E8-A	20:07:22	-44:37:01	10	3	3	3	3	5
E9-A	22:45:37	-44:22:47	10	3	3	3	3	5

[a]Main fields, except for C26202/HST and MaxVis, have previously determined standard stars covering the full DECam focal plane. These full-field-of-view standard fields come from SDSS Stripe 82.
[b]Coordinates offset 5 arcmin to the North in order to place a particular star in the center of the N4 CCD.
[c]Supplementary fields have previously determined standard stars covering a 10 arcmin x10 arcmin region and are typically used for expanding the range of airmasses of observed standards when no suitably placed main field is available. These particular supplementary fields come from the Smith et al. Southern *u'g'r'i'z'* standard stars project (http://www-star.fnal.gov/Southern_ugriz/index.html).

Appendix B: The Functional Form of the Nightly Photometric Equation

The form of the photometric equations for the DES follows closely that for the SDSS[5]:

```
g = -2.5log10(counts/sec) - a_g - b_g*( (g-r) - (g-r)_0 ) - k_g*X
r = -2.5log10(counts/sec) - a_r - b_r*( (g-r) - (g-r)_0 ) - k_r*X
i = -2.5log10(counts/sec) - a_i - b_i*( (i-z) - (i-z)_0 ) - k_i*X
z = -2.5log10(counts/sec) - a_z - b_z*( (i-z) - (i-z)_0 ) - k_z*X
Y = -2.5log10(counts/sec) - a_Y - b_Y*( (z-Y) - (z-Y)_0 ) - k_Y*X
```

where

```
g,r,i,z,Y = the calibrated mags
(g-r),(i-z),(z-Y) = the calibrated colors
(g-r)_0,(i-z)_0,(z-Y)_0 = fiducial (reference) colors
a = photometric zeropoint
b = instrumental color term coefficient
k = first-order extinction
X = airmass
```

The above set of equations is fit nightly and the results are applicable for that night. For a given filter, there are 62 *"a"* coefficients and 62 *"b"* coefficients (one *"a"* and one *"b"* per CCD), but just one first-order extinction (*"k"*) coefficient. The current plan is to fit the instrumental color term *("b")* coefficients nightly, the better to track changes in the filter responses, but it is also possible to fix their values to some fiducial mean values (perhaps updated on a weekly, monthly, or yearly basis). Since the standard stars will be transformed into the "natural" *grizY* system of the DECam+Blanco telescope, where the natural system will be defined by the mean instrumental filter response on the DECam focal plane at the beginning of the survey **(TBD)**, it is expected that the values of the *"b"* coefficients will be quite small (merely tracking the variations in the filter response across the DECam focal plane and versus time over the course of the DES).

The color indices used for the color terms based are on the general DES observing strategy of typically observing science targets in *g* and *r* during dark time and in *i, z, Y* in bright time. Thus, the equations for *g* and *r* are links to the *(g-r)* color index, the equations for *i* and *z* are linked to the *(i-z)* color index, and the equation for *Y* is linked to the *(z-Y)* color index.

Unlike with the science targets, standard star fields observed as part of the evening twilight, middle of the night, and morning twilight dedicated standard star field observations will always be observed in all 5 DES filters, regardless of sky brightness.

[5] http://www.sdss.org/dr7/algorithms/jeg_photometric_eq_dr1.html